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CEILING SYSTEMS DESIGN AND INSTALLATION LESSONS FROM THE CANTERBURY EARTHQUAKES

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Abstract: Damage to ceiling systems resulted in a substantial financial loss to building owners in the Canterbury earthquakes. In some buildings, collapse of ceilings could easily have resulted in severe injury to occupants. This paper summarizes the types of ceiling damage observed in the Canterbury earthquakes, and draws useful lessons from the observed performance of different types of ceiling systems. Existing ceiling manufacturing and installing practices/regulations in New Zealand are critically scrutinized to identify deficiencies, and measures are suggested to improve the practice so that the damage to ceilings and the resulting loss are minimized in future earthquakes.

1. INTRODUCTION

Ceiling systems consist of the ceiling itself, and all the components that may interact with the ceilings. Some common elements interacting with ceilings are partitions, bulk heads, heating, ventilating and air conditioning (HVAC) equipment, electrical equipment, and fire sprinklers. Excessive movement or failure of one of these elements can result in damage to, and/or collapse of, part of a ceiling. Needless to say, utmost care should be taken in installing any of these elements so that the performance of other interacting elements is not adversely affected.

In New Zealand, while there is no restriction on the types of ceiling that may be used in different situations, ceilings in residential dwellings and small ceilings in commercial buildings are commonly constructed with gypsum board. Moderate and large ceilings are more often suspended on a cold-formed steel grid, into which ceiling tiles sit as shown in Figure 1. In these ceilings, the tiles can move a few millimeters in different directions within the grids, so force must be transferred through the grid members, rather than directly between the neighboring tiles. A number of manufacturers provide grid ceilings.

Suspended ceilings are commonly designed to be either fixed to the perimeter walls, or they may be floating. The fixed ceilings are connected to the perimeter walls at least on two sides. When bracing the ceiling off the walls, lateral inertial ceiling forces are taken axially through the tee rails in each direction, to the walls. Axial loads (tension and compression) are at their highest near the walls and at their lowest towards the centre of the room. Each tee rail will be in tension at one end and in compression at the opposite end.

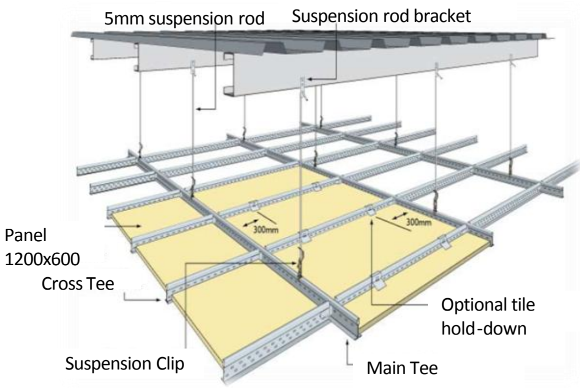


Figure 1. Typical ceiling configuration not showing seismic bracing (based on Rondo, 2009)

On the other hand, floating ceilings are not connected to the wall in any side, but they are braced to the floor or roof above to prevent large movements under service conditions, as well as to transfer horizontal earthquake induced inertia forces. Bracing is normally provided in the form of inclined rods connected to the ceiling grid in one end and the floor at the other end. Typically this system is adopted if tee lengths exceed the maximum length determined for perimeter fixed ceilings.

2. CURRENT DESIGN AND INSTALLATION SPECIFICATIONS FOR CEILINGS IN NZ

Since suspended ceilings are generally developed by companies and are sold as proprietary systems, construction details, element capacities, as well as analysis methods to obtain element demands from global loads are generally provided by companies in their literature, or through discussion with their engineering staff. Mainly, the following documents are used for ceiling system design and installation in New Zealand:

1. NZS 1170.5:2004 – Structural design actions Part 5-Earthquake Actions Section 8 "Requirements for Parts and Components"
2. AS/NZS 2785:2000 – Suspended Ceilings: Design and Installation
3. NZS 4219:2009 – Seismic performance of engineering systems in a building.

In addition to these three, the following standards used in NZ are also relevant to ceiling design/installation and performance assessments:

- Ministry of Works PW/81/10/1:1985 - Guidelines for the Seismic Design of Public Buildings: Appendix D Suspended Ceilings and Associated Fittings and Fixtures
- AS/NZS 1170.1:2002 - Structural design actions - Permanent, imposed and other actions
- AS/NZS 1530.3:1999 - Methods for fire test on building materials, components and structures - Simultaneous determination of ignitability, flame propagation, heat release and smoke release
- AS 2946:1991 - Suspended ceilings, recessed luminaries and air diffusers – Interface requirements for physical compatibility
- ISO 6308:1980 - Gypsum plasterboard - Specification
- ASTM E1414-11 - Standard test method for airborne sound attenuation between rooms sharing a common ceiling plenum (two room method)

In addition to the abovementioned standards, a number of proprietary guides exist in the industry. As these generally follow loading standards older than NZS 1170.5 and may not necessarily be current, it is the designer's responsibility to ensure that they are current before using these guides. Moreover, information on international practice is also available from groups such as the US Federal Emergency Management Agency (FEMA). Until July 2011, only AS/NZS 1170 was listed as a compliance document to the NZ Building Code as specified by the Department of Building and Housing (DBH). However, in 2011, the DBH also listed NZS 4219:2009 as a compliance document for ceiling (DBH 2011).

Some of the key specifications (related to ceilings) provided in the abovementioned regulatory documents are given below:

2.1 NZS 1170.5:2004

1. All parts of structures including permanent, non-structural components and their connections, and permanent services and equipment supported by structures, shall be designed for the earthquake actions specified in this Section.
2. Buildings parts are divided into seven categories, among which ceilings feature in the following categories:
    - Auditorium ceilings: P.2 (Part representing a hazard to a crowd of greater than 100 people within the building)
    - Light suspended ceilings: P.7 (All other parts)
3. Auditorium ceilings (i.e. category P.2) are designed for ultimate limit state (ULS) whereas suspended ceilings (i.e. category P.7) are designed for serviceability limit state (SLS1).
4. Ceilings directly attached/framed to the structure/walls be designed for ductility 3 or less and a suspended ceiling shall not be designed for ductility greater than 2.

2.2 AS/NZS 2785:2000

1. The aim is to provide a ceiling system that has adequate strength and serviceability, is stable and durable, and satisfies other objectives such as economy and ease of construction.
2. Ceiling systems shall be designed and installed in such a manner that the suspension and frame will remain structurally sound, without maintenance, for a period of 15 years.
3. The following limit states are recommended:
    - Ultimate limit state (for life safety): A ceiling has adequate strength if the probability of failure of the system or components is acceptably low throughout its intended life.
    - Serviceability limit state (for operational continuity and business interruption): A ceiling is serviceable if the probability of loss of serviceability of the system of the components is acceptably low and the ceiling maintains its intended performance level throughout its intended life.
4. The methods to design for the ultimate limit state are given as:
    - The ultimate limit state is reached when the ceiling system or part thereof ruptures, becomes unstable, or loses equilibrium.
    - The member or component shall be proportioned such that the design action effect (calculated for the specified loads/actions and load combinations) is not greater than the design ultimate strength (strength reduction factor times the nominal capacity obtained from the material standard or tests).
    - Ceiling hangers shall be proportioned such that the failure or removal of a single hanger does not trigger a progressive collapse of the ceiling system.
5. The method to design for the serviceability limit state is given as:
    - The total deflection of the ceiling shall take into consideration the deflection of the suspension system, and remain within the specified limits (between L/250 and L/600).

2.3 NZS 4219:2009

1. Suspended ceilings are outside the scope of this standard; only equipments interacting with ceilings are covered by this standard. Where service loads are greater than 3 kg/m^2, the ceiling designer should be advised.
2. Suspended ceilings should be designed and constructed in accordance with AS/NZS 2785.
3. Equipment supported by the ceiling not exceeding 10 kg shall be positively fixed to the suspension system but not supported by the ceiling panels or tiles.
4. Suspended ceilings, equipments in ceiling voids and supported by the ceiling are considered as dead load.
5. Service loads greater than 3 kg/m^2 (0.03 kPa) need special consideration.
6. Equipment with a mass less than 10 kg shall be supported by the grid of the suspended ceiling system. Equipment exceeding 10 kg mass shall be supported independently of the ceiling.
7. Equipment supported independently of the ceiling shall have a clearance of 25 mm all round to allow independent movement between component and the ceiling.
8. Ceiling suspension components (hangers, braces, and so forth) shall be located with specified clearances. A minimum of 50 mm clearance in the vertical and horizontal direction is recommended between restrained components (i.e. ceiling hangers and braces).
9. A minimum clearance of 150 mm in horizontal and 50 mm in vertical direction is recommended between unrestrained components and restrained components.
10. All fixings of hanging luminaries shall be positive, locking type to prevent disengagement.
11. Where luminaries are recessed or surface-mounted on suspended ceilings, they shall be positively clamped to the ceiling suspension systems. Clamping shall be by means of screw and nuts or locking-type clamping devices.

3. ISSUES WITH CURRENT NZ DESIGN PROCEDURES AND PRACTICE FOR CEILINGS

A number of concerns have been expressed by designers, contractors and fabricators on different aspects of the existing ceiling design and installation practice. Some of these concerns are listed below:

3.1 Performance Objectives

- Suspended ceilings are included in the least important category (Category 7 in the recommendations in NZS 1170.5 Clause C8.1) considering the lowest level of design demand (SLS1). The required design level for ceilings may be too low as evidenced by the fact that a number of ceilings were replaced several times in Christchurch during the Canterbury earthquake sequence.
- Life safety threat from ceilings is not fully acknowledged. There were fatalities resulting from ceiling damage in the 2011 Japan earthquake. It is only a good fortune that there was no life loss as a result of the several ceiling collapses in the 2010-2011 Canterbury earthquakes. It seems that ceilings should be designed to have no possibility of causing death/injury during ULS shaking to be consistent with the NZ Building Code.
- If performance objectives become too conservative, this may mean that suspended ceilings will stop being a reasonable design option. This could have a significant adverse effect on the suspended ceiling industry.

3.2 Ceiling Standards

- Some standards are not up-to-date and reference out-of-date standards (e.g. AS/NZS 2815).
- The standards do not emphasize or state specific requirements to ensure good ceiling system performance, such as the gap-size between a floating ceiling and the wall, or how to consider interactions with specific service components.
- Floor acceleration profiles in current standards (NZS1170.5 and NZS4219) are the same up the building height for all building types. In reality, different building types have different accelerations at different heights, so this may result in some conservatism/non-conservatism.

3.3. Assessment of Ceiling Capacity for Design

- Test protocols are available for ceilings. Many of these require shaking table testing, which is too demanding.
- There is no method of relating test protocol results to design.

3.4 Ceiling Design Practice Issues

- No generic information is available on the principles involved in designing ceilings and providing bracing.
- There is a lack of generic design examples, especially regarding lateral bracing.
- Often ceiling systems are designed by engineers who are not the building designers and information necessary for ceiling design is not readily available. This includes the likely accelerations and drifts. It takes time and cost to obtain these parameters from an analysis of the building, and requires knowledge of things such as the soil conditions if the analysis is to be done accurately.
- Ceiling examples are often not checked.
- The documents required by AS/NZS 2785 (Appendix C) for conducting basic design of ceilings (i.e. drawings and documentation on

interaction of the ceiling system and building services) are seldom provided at tender or consent time.

3.5 Installation Issues

- There is a significant amount of poor installation.
- The NZS 4219 recommended minimum clearances between the ceiling and equipment supported independently of ceilings are often not being adhered to in practice.
- Component connection is often inadequate.
- Inappropriate connection of ceilings to suspended services (such as ducts), or a lack of ceiling support being provide around services.
- There is a lack of training opportunity for installers. Hence, many installers have very limited training. No training is required for installation in general.
- While NZS 4219 requires all fixings between hangings of luminaries along with ceiling grid system to be positive (locking type) to prevent disengagement, there are no examples and illustrative sketches provided; thereby leaving room for misinterpretation leading to faulty details.
- Often, there is a lack of inspection.
- Ceiling inspectors are often not trained.

3.6 Political Issues

- Ceiling design is generally considered as an afterthought, rather than as part of the major building contract.
- The tasks of building structure design/construction, service equipment design and placement, partition design/installation and ceiling design/installation are often conducted separately or with little interaction between these groups. Therefore, coordination often does not occur to ensure that each of these parts acts as required.
- Often ceiling design has not been completed at the time of the tender for installation. Also, fees for ceiling design are seldom included in the tender. Responsible contractors, who pay for the ceiling design and pay the building design engineer, therefore have a high contract price. Other installers, who do not perform the full design have lower contract prices and often win the contracts. As a result, the current system discourages rigorous design.
- Anecdotal evidence suggests that the prices for ceilings in Christchurch are some of the lowest in NZ. Also, the quality of installation is correspondingly low.
- Changes to building use or occupancy often result in changes to the building internal layout with movement of partitions and installation of different ceilings. This can result in poor seismic behavior if appropriate precautions are not made.

4. SUMMARY OF CEILING DAMAGE OBSERVED IN CANTERBURY EARTHQUAKES

The damage observed to suspended ceilings described below during the recent Canterbury earthquakes includes that sustained during the September 2010 Darfield earthquake (Dhakal 2010; MacRae et al 2011) as well as the February 22nd and 13th June 2011 Christchurch earthquakes (Dhakal et al 2011). This has been organized by damage type: grid damage; perimeter damage; interaction with other components; grid spreading; and combinations of different damage types.

4.1 Grid Damage

Grid damage results from excessive force on the grid members or connections. This then results in ceiling grid distortion under compression and subsequent buckling of the grid members or failure of the connections while the perimeter connections remain intact. Below are several examples of ceiling grid damage observed in the Canterbury earthquakes.

Figure 2a. Damage resulting from disconnection of cross-tee from the main beam resulting in localized collapse of the grid and loss of tiles (Photos: K Hogg)

Figure 2b. Damage to grid members due to excessive compression force (Photos: K Hogg)

Figure 2c. Damage resulting from main beam splice failure (left) and cross-tee disconnection with main beam (right) (Photos: Hush Interior Ltd)

Figure 2d. Damage resulting from main beam splice connection (left) and buckling of cross-tee connections and main beam splice failure (right) (Photos: K Hogg)

The uniformly distributed mass (in the form of tiles) in a ceiling generates uniformly distributed inertial force, and the accumulated inertial force which causes axial compression in the grid members becomes greater near the supports (i.e. the perimeter) than in the middle (Paganotti et al 2011). In general, the observed compression damage of grid members was hence more severe near the perimeter, whereas failures due to tension and connection fracture did not follow a specific spatial pattern.

4.2 Perimeter Damage

Perimeter damage results from the main tee or cross-tee losing seating on the perimeter angle around the ceiling. Loss of seating can result due to a lack of a rivet to connect the grid member to the angle or failure of the rivet itself. This results in the grid members and tiles dropping from the ceiling. Edge perimeter hanging wires can prevent the member and tiles from falling, however, this can result in the tile and members being forced back into the angle causing damage to the tiles and members; see Figure 3a (right) below.

Figure 3a. Damage caused by disconnection of main beams and cross-tees. Note damage to panels at right which have not dropped from the ceiling but have been forced back into the wall angle causing damage (Photos: Hush Interior Ltd)

Figure 3b. Damage caused by failure of rivet between main beam/cross-tee and wall angle (Photos: Hush Interior Ltd.)

Common current practice is to connect the grid members to the perimeter angle with centre single-size riveting which only connects to the face cap. Such a riveting system was found to be inadequate. In some cases, the inadequate rivets were observed to fail in tension, leaving only the aluminum cap to hold the system together. In other cases, the rivets were also found to have ripped through the steel wall angles and tee rails. Probably, the standards need to provide detail specifications on the number, size and locations of rivets for such perimeter connections.

In one case, during repair after the February earthquake damage, engineered tee connections were provided with an increased number and diameter of rivets. This detail survived the June 13 earthquake and the quakes afterwards. Only the trim suffered a small amount of distortion. A photo of this connection is shown in Figure 3c.

Figure 3c. Perimeter connection with increased number/diameter of rivets (Photo: K Hogg)

4.3 Interaction with other Equipments

Damage to suspended ceilings can result from force transferred from services above the ceiling into the ceiling itself. In a standard installation of a suspended ceiling the hanger wires are placed at 1200 mm centre. However, the presence of services (such as HVAC) above the ceiling can mean this is not possible. As a result suspended ceilings are sometimes partially hung from services within the ceiling (most commonly HVAC ducting and plant). As this plant is rarely secured properly, when it moves it imparts force into the ceiling, causing damage. Additionally, services above the ceiling moving during an earthquake can impact the hanging wires of the suspended ceiling, once again imparting force into the ceiling. Suspended ceilings are not designed to take the additional force from this plant. Grills within the ceiling plane were often observed to have fallen from the ceiling and localized loss of tiles often occurred around the location of these grills. Some instances of ceiling failures resulting from the interaction with the services are shown in the figures that follow.

Figure 4a. Damage caused by interaction with services above the ceiling (Photos: Hush Interiors Ltd.)

Figure 4b. Damage caused by unbraced AC ducts swaying o or causing damage (Photos: R Dhakal, K Hogg)

In some buildings the ducting sizes make it difficult to provide hangers at the required spacing and the service heights provided were too low to provide proper bridging under services. Figure 4c below shows cases like these.

Figure 4c. Damaged ceiling with inadequate service height (Photos: K Hogg)

Interaction with partition walls also caused damage to some ceilings braced to the walls. Some internal walls extend to the floor above and are fixed either directly to the floor or beam or through inclined braces which are required to minimize buckling of slender walls. In some cases the ceiling may also be supported on these internal walls. The braces of these walls are close to the ceiling hangers and other equipment braces and are likely to interact with the system. It was found that the failure of the braces (some of which fell off) could easily have caused significant damage to the ceilings (see Fig 4d left).

Figure 4d. Interaction between internal walls and ceiling (Photos: K Hogg)

In some cases, the partition walls stopped at the ceiling level and were braced by ceilings. Obviously, in such cases the ceiling needs to cater for the wall as well. Glazed partitions fall into this category, and due to small aluminum sections they are difficult to brace. In some buildings, such wall partitions were found to be out of plumb and in one glazed partition, glass jumped out of the top track (see Fig 4d right).

4.4 Grid Spreading

The suspended ceilings discussed in the previous sections are all two-way exposed grid systems. That is, they consist of a two-way grid of inverted 'T' shaped members hung from the ceiling above. The panels are then dropped in and rest on the flanges of the inverted 'T' sections.

The damage shown in the photos below occurred to grids that are different to the two-way type grid discussed in the previous sections of this report. The grids below consist of main beams spanning one way and hung from the structure above. There are typically no transverse runners (except where the ceiling may have been retrofitted with these). The drop-in panels prevent the grids from spreading apart during an earthquake. However, if panels do drop out there are no members to stop the grids moving apart (spreading) and causing further panels to fall from the ceiling. Also, as opposed to the two-way systems discussed above, the panels are not supported on all four edges by the grid system. The panels are instead interlocked, so when one panel falls it leaves the next panel susceptible to falling.

Figure 5. Damage caused by grid spreading causing the panels to fall from the ceiling (Photos: T Abu and Hush Interior Ltd)

4.5 Other Types of Damage

Damage to suspended ceilings can also result from elements that are connected to the ceiling but should be independent of it. Common examples of this are timber or steel framed bulkheads and partitions. Partitions, in particular, should not rely on lateral support during an earthquake from the suspended ceiling. Unless it is considered explicitly in design, this type of construction applies extra force into the ceiling and can result in damage (see Fig 6a for example).

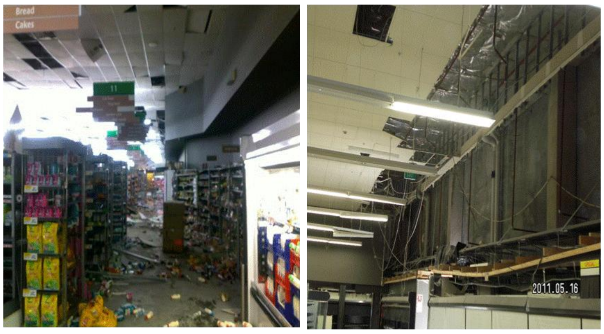


Figure 6a. Damage due to interaction between bulkheads and ceiling (Photos: K Hogg)

In some cases damages were attributable to the interaction between ceilings and bulkheads. Bulkheads hanging from tiled ceilings dropped when the ceiling perimeter detail failed. In a building it was found that during renovation, bulkheads were removed but no bracing was put in place to take the ceiling load. In such cases, the partition loads change during alterations and ceiling line load increases, hence it is advisable to provide bracing to take care of the increased load on ceiling.

The above forms of damage can occur simultaneously during an earthquake causing widespread damage to a single ceiling system. Some examples of this are shown in the figures below.

Figure 6b. Widespread damage of a single ceiling (Photos: R Dhakal, T Abu and Hush Interior Ltd.)

4.6 Summary of Observations

- Compression failure generally occurred closer to the perimeter (than the middle) of two way grids.
- Compression failures were observed to be more severe and more extensive in larger ceilings.
- Ceilings with heavier tiles/panels were observed to undergo more severe damage compared to those of the same size with lighter tiles in the similar shaking region.
- Observed damage in ceilings was very severe in many cases and it was only a coincidence that nobody was killed due to ceiling failure in these earthquakes. As the 2011 Japan earthquake has proved, heavy ceiling tiles falling from several meters can easily be fatal. Even in rooms without heavy tiles, cross members bent down like skewers, causing a major hazard for anyone evacuating the building.
- Interactions with services above the ceilings, partition walls and bulkheads were found to cause many ceiling failures. This was most significant when services/walls were not constrained and interacted with the ceiling.
- Some ceilings were replaced several times during the earthquakes indicating that they were not able to sustain the levels of shaking imposed.
- Poor performance often resulted from poor system installation.

5. RECOMMENDED PRACTICE – DESIGN AND INSTALLATION GUIDANCE FOR CEILING SYSTEMS

A series of brain storming meetings was held between ceiling researchers and practitioners (designers, manufacturers, installers etc) to scrutinize the observed ceiling damage and to come up with immediate measures to improve the performance of ceiling systems in future earthquakes. As a result, the following “recommended practice” guidelines are proposed for ceiling systems, which include the ceiling itself, and all interacting elements:

5.1 Technical recommendations

1. All ceiling systems be designed and installed following appropriate standards.
   - NZS 1170.5:2004: for calculating the seismic demand on ceiling systems
   - NZS 4219:2009: for designing services and their interaction with the ceiling
   - AS/NZS 2785:2000: for designing ceilings
2. While using NZS 1170.5 to determine the design limit state, ceilings shall be placed in the following categories:
   - P.2 – Auditorium ceilings
   - P.3 – Suspended ceilings with one way or two way grid systems
   - P.4 – Suspended ceilings with heavy (more than 10kg) tiles
   - P.7 – All other ceilings
3. If interstorey displacements are not available from the design engineer and they are not computed explicitly, then:
   - the minimum ULS drift ratio demand shall be of 2.5% at all stories
   - the minimum SLS1 drift ratio demand shall be one third of the ULS value above
4. If floor accelerations are not available from the design engineer and they are not computed explicitly, then:

- the minimum ULS acceleration demand shall be 3 times the zone factor, Z, at all levels
- the minimum SLS1 acceleration demand shall be one third of the ULS value above

5. Ceiling connections shall be designed for a ductility of 1.25 for the ULS unless it is shown that another value is satisfactory.
6. Equipment with mass less than 5 kg (per m^2 of ceiling area) may be supported by the grid of the suspended ceiling system, and those exceeding 5 kg mass shall be supported independently of the ceiling. This recommendation overrides the existing statement in Clause 5.13 in NZS 4219:2009.

5.2 Regulatory recommendations

1. If the installer is required to provide the ceiling system design, the following is to be provided by the building design engineer in the tender documents:
   - floor accelerations for SLS and ULS actions.
   - interstorey displacements for SLS and ULS actions.
2. Design and detailing of ceilings and components interacting with ceilings (giving due consideration to the interactions between them) is to be undertaken under the supervision of a Chartered Professional Engineer.
3. Construction of ceilings and services is to be undertaken by a trained and experienced installer.
4. Construction review is to be undertaken by a suitably qualified engineer; preferably the designer.
5. Structural modifications to components interacting with ceiling systems shall consider the implication of the modification to the ceiling.
6. For quality control, the building consent documentation is to define who is responsible for the following design, installation and certification/review processes:
   - Producer Statement 1 (PS1) – Design
   - Producer Statement 3 (PS3) – Construction
   - Producer Statement 4 (PS4) – Construction Review

   If the ceiling is a design and supply item the tender documents shall spell out the requirement for each of these.
7. AS/NZS 2785 needs to be updated in line with the seismic demand stated in NZS 1170.5.
8. Training programmes and qualifications need to be made available for installers.

It is likely that some clients will request buildings and non-structural components, such as ceilings, be designed for greater performance than that associated only with life safety. Also insurance companies may require this in Christchurch and elsewhere as a result of the significant damage resulting from the Canterbury earthquakes. Improved performance may be obtained by designing components greater levels of ground shaking, such as the NZS 1170.5 Maximum Considered Event (MCE) which is defined as being 1.8 times the NZS 1170.5 Ultimate Limit State (ULS) Event. Alternatively, it is possible to design for higher serviceability criteria. In addition, damage may be minimized by using the details recommended below.

6. BEST PRACTICE DETAILING GUIDE FOR CEILINGS

1. Rivets should be placed on the side of a T-section, to go through two, rather than one piece of steel which is the case if they are placed in the middle.

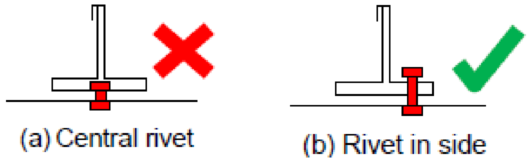


Figure 7a. Locations of rivets in T-rails (Elevation)

2. Rivets be placed with sufficient distance to the end of T-rails so they can develop their full strength.

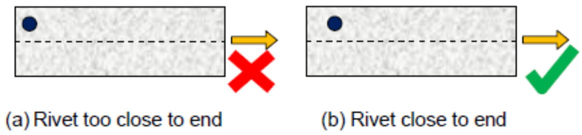
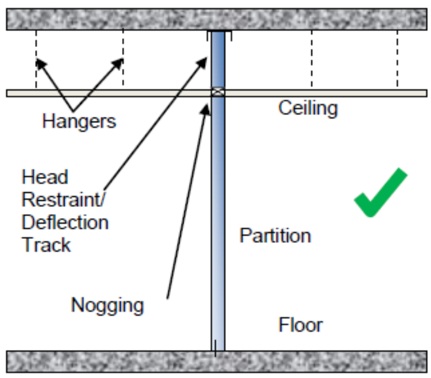
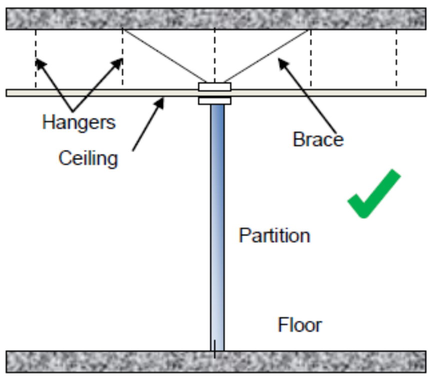


Figure 7b. Locations of rivets in T-rails (Plan)

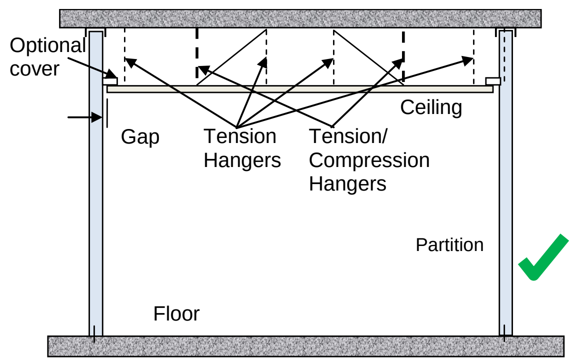
3. It should be clear whether partitions are bracing the ceiling, ceiling is bracing the partitions, or whether they are independently braced as shown in the Figures below. A head-restraint can be used at the top of the partition. This restrains the partition in the out-of-plane direction. Note that hangers which go to the bottom end of a vertical brace must resist both compression as well as tension, as shown in Figure 7c, in order to prevent large ceiling swinging displacements.
4. Ceilings should be protected from ducts hanging from floor preferably by strongbacks with sufficient space for bridging.
5. Flexible chords should be used for fire sprinklers, or sufficient gaps should be provided in the ceiling so that large forces are not imposed.
6. Lighter tiles should be used rather than heavy tiles as light ceiling systems are likely to sustain less earthquake damage.



(a) Partition Bracing Ceiling

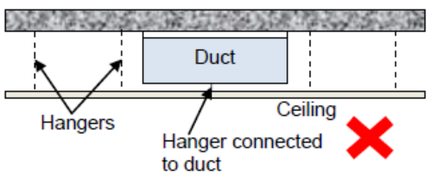


(b) Ceiling Bracing Partition

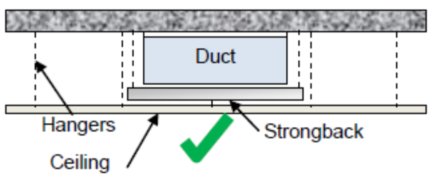


(c) Ceiling and Partition Independently Braced (Floating ceiling)

Figure 7c. Some examples of ceilings/partition configurations



(a) From Duct (Undesirable)



(b) From Strongback (Desirable)

Figure 7d. Suspension of ceiling hangers around ducts

Acknowledgement:

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